Stability of glass-encapsulated disc-type thermistors

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ABSTRACT

Approximately fifteen years ago the Temperature Section of the National Bureau of Standards conducted a stability test on numerous bead-in-glass and disc thermistors. The results indicated that the bead-in-glass thermistors were reasonably stable, but that the disc thermistors showed a definite drift pattern over the two-year test period.

Several years ago, a glass-encapsulated disc thermistor was developed commercially[1] that was advertised as being a "super-stable" precision thermistor." Since February 1989, three such glass-encapsulated disc thermistors were repeatedly calibrated by comparison with a standard platinum resistance thermometer at 25 °C, 60 °C and 90 °C in a stirred-liquid constant-temperature calibration bath. The results of these tests are presented in this paper.

SUBJECT INDEX Thermistors

INTRODUCTION

Because of the increased use of thermistors, especially by the biomedical community, in the late 1970's the National Bureau of Standards (NBS), now the National Institute of Standards and Technology (NIST), conducted an extensive test on thermistors to determine their stability (1). Bead-in-glass and disc thermistors were chosen, because they were the ones used for medical applications. Such thermistors are composed of a mixture of metal oxides and dopants to produce the desired resistance value. Thermistors having values of 1, 2, 5, 10, 15, and 30 kΩ at 25 °C were obtained from the six manufacturers who sold the largest number to clinical laboratories and to medical instrument manufacturers. Several of each type were held at constant temperatures of 0 °C, 30 °C, and 60 °C for a period of approximately 550 to 770 days. The temperature of the calibration bath medium and the resistance of the thermistors were measured and recorded throughout this time period, frequently at first and less often towards the end.

Analysis of the data showed that the bead-in-glass thermistors had little or no observable drift. A plot of the temperature change versus the time in days at that temperature showed a scatter of the data points. The data for the disc thermistors, on the other hand, showed a definite drift which increased in magnitude as the test temperature increased. Figure 1, taken from (1), is a graph showing the typical drift rate for disc thermistors held at 60 °C for a period of 560 days.

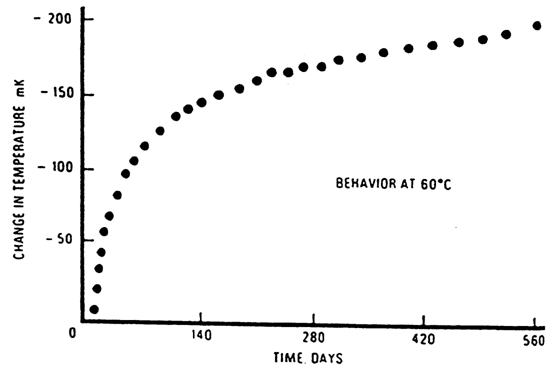

Fig. 1. Typical exponential-type behavior of a disc thermistor held at 60 °C (from the late 1970's study).

DEVELOPMENT OF A "SUPER-STABLE" DISC THERMISTOR

Since the test described above was conducted, so-called "super-stable" disc thermistors have been developed. The most accurate one advertised has a 10 kΩ zero-power resistance at 25 °C with a tolerance of ±0.24% of the resistance value in the range of 0 to 70 °C. The commercial literature states that the superior performance is achieved by replacing the standard epoxy coating with a glass hermetic encapsulation and a 100% individual in-process screening. The manufacturer states an interchangeability of ±0.05 °C from 0 to 70 °C, a better than ten-fold increase in long-term stability (typically within ±0.005 °C of its initial value for a minimum period of one year at all use and storage temperatures below 70 °C), and a recommended operating range not to exceed -80 to +200 °C.

Since disc thermistors can easily be made interchangeable, it would be advantageous if they could be made as stable as the bead-in-glass thermistors. This study was conducted to determine the stability of such disc thermistors.

EQUIPMENT USED FOR THE EVALUATION

Three of the disc thermistors were obtained by NIST for evaluation. The thermistors were repeatedly calibrated by comparison with a standard platinum resistance thermometer (SPRT) (2). The SPRT was made

[1] Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

by Cyril H. Meyers and has been used in the Liquid-in-Glass Thermometer Calibration Laboratory for over 30 years. Over the past 15 years, its resistance at the triple point of water has changed less than the equivalent of 0.002 °C.

A Cutkosky ac resistance bridge (3) that has been in use in the laboratory since 1975 was used to measure the resistance of the SPRT. The SPRT and the Cutkosky ac resistance bridge were calibrated together as a system in the Platinum Resistance Thermometry Laboratory at NIST. Tests conducted before the bridge was put into service indicated that the reading was in error by no more than 3 μΩ over the range of 0 to 100 Ω. The SPRT-bridge combination showed a change in resistance at the triple point of water, which was measured every day that data were recorded, equivalent to less then 0.001 °C over the two-year period.

The thermistors and SPRT were placed in a commercial calibration bath, using distilled water as the medium. The working volume of the bath was 100 mm in diameter by 450 mm deep and contained about eight liters of water. The water was pumped up through an inner tube and overflowed into the annulus between the inner tube and the wall of the bath, forming a meniscus on the top of the inner tube. Temperature stability was determined to be ±0.0005 °C at 25 °C and 60 °C and ±0.001 °C at 90 °C. Measured non-uniformity, both horizontal and vertical, were found to be 0.001 °C at 25 °C and 60 °C and 0.004 °C at 90 °C.

The thermistors were connected as four-lead devices. Two leads were used to measure the voltage across the resistance element and the other two leads were used to supply current to the thermistors. The current leads of the three thermistors were connected in series. Also connected in series with the thermistors was a 10 kΩ precision resistor, which was used to calculate the current in the system. When calibrated, approximately every six months, against a high-stability transportable standard resistor, the value of the precision resistor varied by no more then 0.01 Ω over the two-year period. The standard resistor was recalibrated on February 16, 1990 and the change in resistance from the previous calibration, conducted before this study began, was 0.003 Ω.

A commercial high-stability constant current source was used to supply current to the system. The manufacturer's specifications state that the unit has an accuracy of 0.05% and a long-term stability of 20 ppm/1,000 hours. Any fluctuation in the current could be detected, since the voltage across the precision resistor was measured at each temperature.

The voltage across the precision resistor and each thermistor was read using a 6.5-digit digital voltmeter, that was set for a six digit resolution.

CALIBRATION PROCEDURE AND CALCULATION OF DATA

Each thermistor originally had two leads, which were 8 cm long. The thermistors and the 10 kΩ precision resistor were connected in series and attached to the constant current source. In order to measure the voltage across each thermistor and precision resistor, extension wires, approximately 103 cm long and 30 gauge, were soldered to each side of the resistance elements. The voltage leads from the thermistors were connected to a manually operated switching box, which permitted the voltage across any one of the three thermistors to be read on the digital voltmeter. A diagram of the circuit is shown in Fig. 2.

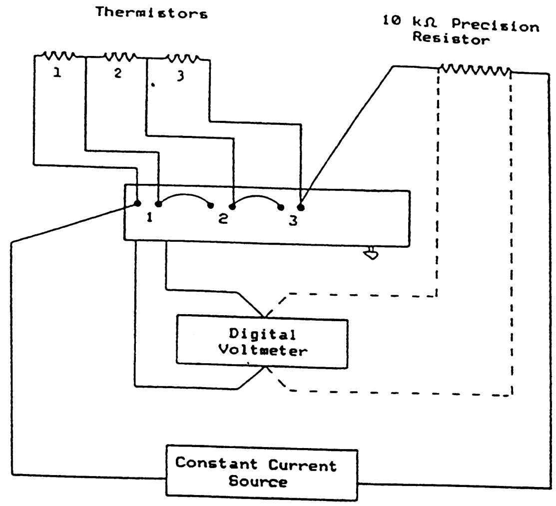

Fig. 2. Wiring diagram showing the connection of the thermistors to the manually operated switching box, precision resistor, constant current source, and digital voltmeter.

For all of the resistance measurements, the three thermistors were placed in a test tube which was 6 mm in diameter. To increase thermal conductivity, a depth of approximately 15 mm of mineral oil was placed in the bottom of the tube, completely immersing the thermistors.

Before any data were taken each day that a calibration was performed, the SPRT was placed in a triple-point-of-water cell and the resistance value was measured and recorded. That value was used in the calculation of the temperature of the calibration bath medium. It was also compared to previous readings to determine whether the measurement system was still in calibration.

The test tube containing the thermistors was immersed 25 cm in the constant-temperature water bath. In order to minimize the error due to gradients in the bath, the SPRT was immersed in the water bath with the center of the platinum coil in a horizontal plane with the thermistors. The SPRT coil was approximately 2.5 cm from the three thermistors. The thermistors were calibrated at 25 °C, 60 °C, and 90 °C. They were removed from the bath and remained at room temperature (23 °C) until the next calibration. At 25 °C the refrigeration unit of the calibration bath was activated in order to obtain a regulated temperature. It was not needed at 60 °C or 90 °C.

Data were taken at each calibration temperature, after the temperature of the bath was stabilized (within 0.001 °C). The voltage across the precision resistor was measured, first with the current flowing in one direction and then with the current flowing in the opposite direction.

Values were obtained from the SPRT and thermistors and were recorded in the following sequence:

1) The resistance value of the SPRT,
2) The voltage across each thermistor (1 through 3) with the current flowing in one direction,
3) A second resistance value of the SPRT,

4) The voltage across each thermistor (3 through 1) with the current flowing in the opposite direction, and
5) A third resistance value of the SPRT.

The voltage across the precision resistor was again measured.

An average of the three resistance values recorded for the SPRT was divided by the corrected resistance value determined that day for the triple point of water. This resistance ratio was used to calculate the temperature of the calibration bath medium.

The two voltage values for each of the three thermistors were averaged, as well as the four voltage values that were measured across the precision resistor. Knowing the resistance value of the precision resistor and the voltage across it during calibration, the current in the system was calculated using Ohm's law. Knowing the current in the system and the voltage across each thermistor, the resistance of each thermistor was calculated, again using Ohm's law.

The change in resistance with temperature (dR/dT) was calculated for each thermistor at each temperature and the data were adjusted so that the resistance values corresponded to the values at 25 °C, 60 °C, and 90 °C. An average of the 27 resistance values was calculated for each thermistor at each temperature. Graphs of the temperature deviation (in mK) from the average versus days were made and given as Figs. 3 through 11.

ANALYSIS OF RESULTS

The data as depicted on the graphs indicate no significant drift in the glass-encapsulated disc thermistors. The scatter is similar to the data obtained for bead-in-glass thermistors in the study (1) that was conducted in the 1970's. At 25 °C the deviation in the temperature from the average was slightly less then ±0.0015 °C. As the temperature increased, so did the deviation from the average. The deviation in temperature from the average at 60 °C did not exceed ±0.002 °C, and at 90 °C, it was ±0.003 °C.

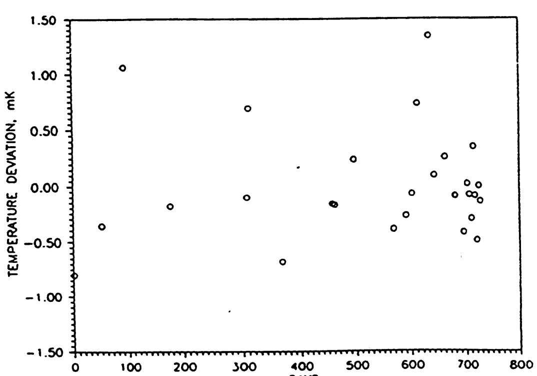

Fig. 3. Temperature deviation from the average in mK versus days for thermistor 1 at 25 °C.

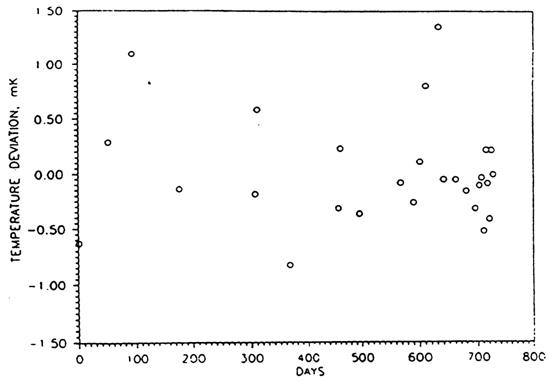

Fig. 4. Temperature deviation from the average in mK versus days for thermistor 2 at 25 °C.

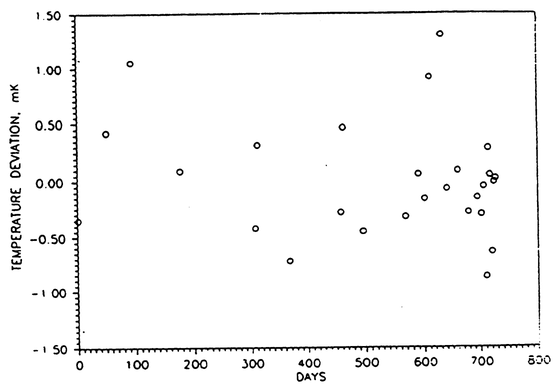

Fig. 5. Temperature deviation from the average in mK versus days for thermistor 3 at 25 °C.

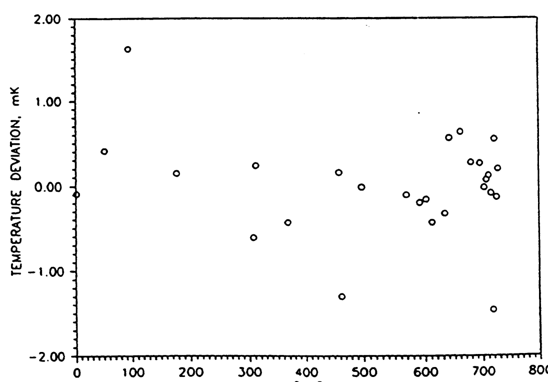

Fig. 6. Temperature deviation from the average in mK versus days for thermistor 1 at 60 °C.

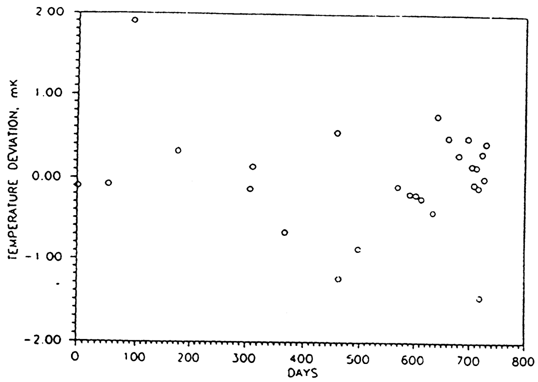

Fig. 7. Temperature deviation from the average in mK versus days for thermistor 2 at 60 °C.

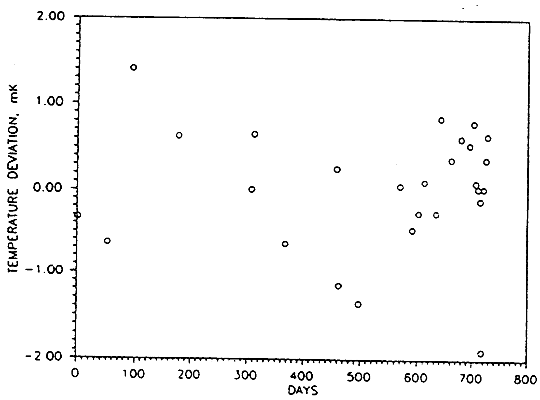

Fig. 8. Temperature deviation from the average in mK versus days for thermistor 3 at 60 °C.

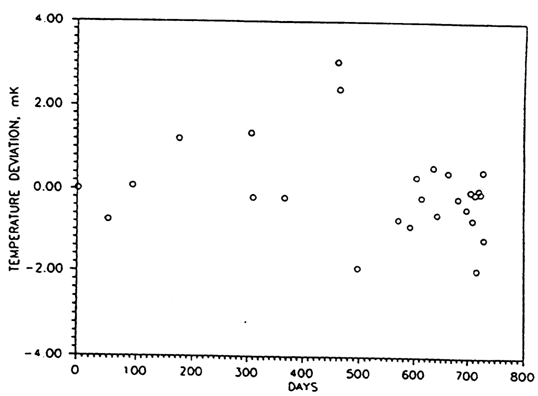

Fig. 9. Temperature deviation from the average in mK versus days for thermistor 1 at 90 °C.

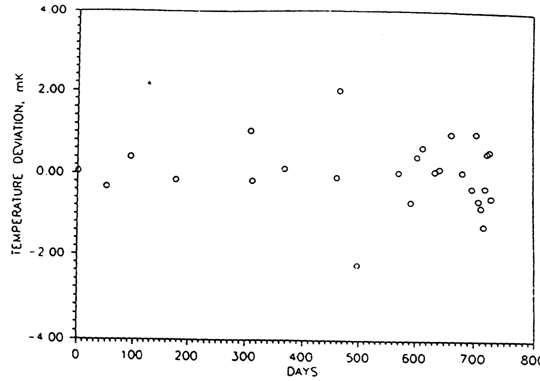

Fig. 10. Temperature deviation from the average in mK versus days for thermistor 2 at 90 °C.

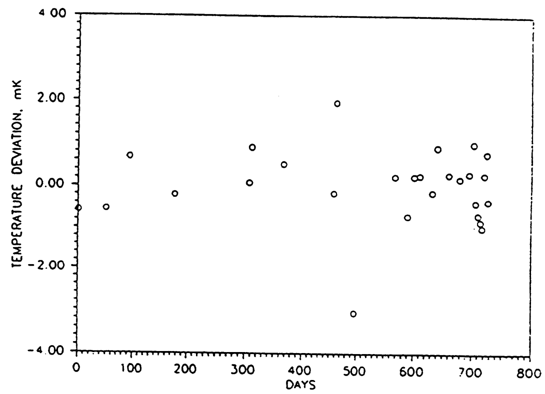

Fig. 11. Temperature deviation from the average in mK versus days for thermistor 3 at 90 °C.

CONCLUSION

The data obtained from the repeated calibration of three "super-stable" 10 kΩ glass-encapsulated thermistors taken over a two-year period indicated that no significant long-term drift (0.001 to 0.002 °C per year) occurs. Also, it can be concluded that the devices are comparable to or only slightly more unstable then bead-in-glass thermistors. In the 25 °C to 90 °C range, the stability was found to be ±0.0015 °C to ±0.003 °C.

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(3) Cutkosky, R. D., An AC Resistance Thermometer Bridge, J. Res. Nat. Bur. Stand. (U.S.) 74C (Engr. and Instr.), Nos. 1 and 2, 15-18 (1970).